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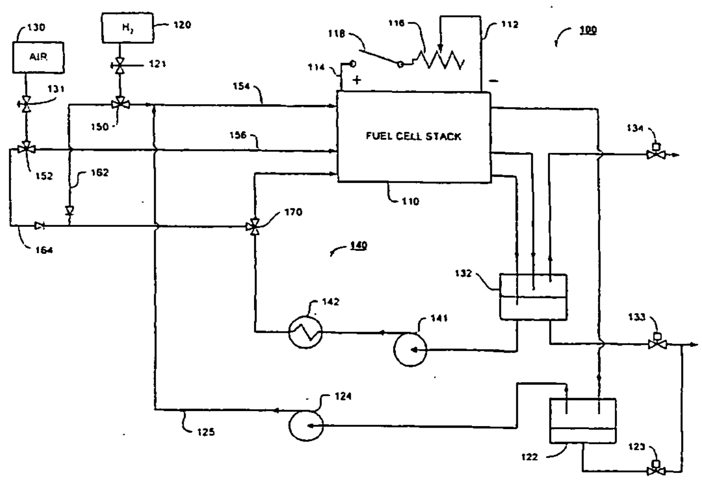
(54) Title: METHOD AND APPARATUS FOR INCREASING THE TEMPERATURE OF A FUEL CELL STACK




(57) Abstract: Disclosed herein are methods and apparatus for increasing the temperature of a solid polymer electrolyte fuel cell stack. In one embodiment, the fuel cell stack comprises a coolant pathway (140) for directing a coolant fluid stream through the stack, and the method comprises supplying at least a portion of each of the fuel and oxidant streams (162, 164) to the coolant pathway, and combusting the fuel and oxidant therein, such that the temperature of the fuel cell increases. In another embodiment, the method comprises monitoring at least one operating parameter of the fuel cell stack indicative of temperature, and supplying at least a portion of both of the fuel and oxidant streams to at least one of the reactant passages in response to the at least one operating parameter, and combusting the fuel and oxidant therein such that the temperature of the fuel cell increases. A device for facilitating combustion of fuel and oxidant within the coolant or reactant pathways, for example, a catalyst, may be incorporated therein.

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# METHOD AND APPARATUS FOR INCREASING THE TEMPERATURE OF A FUEL CELL STACK

## FIELD OF THE INVENTION

The present invention relates to methods and apparatus for increasing the temperature of an electrochemical fuel cell stack or a portion thereof. More particularly, the method comprises combusting fuel and oxidant within coolant or reactant pathways within the stack to increase the temperature of the fuel cells in the stack. The method may be used, for example, during start-up or during operation of the stack when the temperature of the fuel cells is below the preferred operating temperature range.

## BACKGROUND OF THE INVENTION

Electrochemical fuel cells convert reactants, namely fuel and oxidant fluid streams, to produce electric power and reaction products, including heat and water. Solid polymer electrochemical fuel cells generally employ a membrane electrode assembly ("MEA") comprising a solid polymer electrolyte or ion exchange membrane between two porous electrically conductive electrode layers. The anode and cathode each comprise electrocatalyst, which is typically disposed at the membrane/electrode layer interface, to induce the desired electrochemical reaction.

Two or more fuel cells can be electrically connected together in series or parallel to increase the overall power output of the assembly. Such a multiple fuel cell arrangement is referred to as a fuel cell stack and is usually held together in its assembled

state by tie rods and end plates or by compressive bands. The stack typically includes inlet ports and manifolds for directing the fuel stream and the oxidant stream to the individual fuel cell reactant flow passages. The stack also commonly includes an inlet port and manifold for directing a coolant fluid stream, typically water, to interior passages within the stack to absorb heat generated by the fuel cell during operation. The stack also generally includes exhaust manifolds and outlet ports for expelling the depleted reactant streams, and the reaction products such as water, as well as an exhaust manifold and outlet port for the coolant stream exiting the stack. In a power generation system, various fuel, oxidant and coolant conduits carry these fluid streams to and from the fuel cell stack.

Electrochemical fuel cells can operate using various reactants. For example, the fuel stream may be substantially pure hydrogen, methanol reformate or natural gas reformate, or a methanol-containing stream in a direct methanol fuel cell. The oxidant stream may be, for example, substantially pure oxygen, oxygen-containing air, or oxygen in a carrier gas such as nitrogen.

In some applications, fuel cell systems may operate almost continuously (e.g., certain stationary power applications). However, in other applications, fuel cell systems may be subjected to frequent start and stop cycles and to prolonged storage periods between operation periods (e.g., portable and vehicular applications). Further, in colder climates,

such fuel cell systems may frequently be subjected to temperatures below freezing. Such systems therefore must tolerate exposure to sub-zero temperatures without degradation. Additionally, the power output capability from fuel cells is typically limited at temperatures well below the normal operating temperature range, the preferred such range typically being from about 50°C to 120°C. Thus, it is also desirable to be able to start up such systems and bring them up to normal operating temperature in a timely, energy efficient manner, and to maintain the temperature within a desirable range during operation.

A conventional approach for starting up a fuel cell stack is to employ an external power source (e.g., storage battery) or a heater to heat the stack up to a temperature at which fuel cell operation is commenced. However, this requires additional equipment just for start-up purposes. Problems encountered when the temperature is below freezing may be avoided by preventing the fuel cell temperature from going that low, either by operating the fuel cell stack continuously or by heating the stack when it is not in use. In many applications, however, this is not practical.

Various methods for the in situ oxidation of carbon monoxide ("CO"), in order to prevent poisoning of the electrocatalyst in solid polymer electrolyte fuel cells, employ the addition of small quantities of oxygen to the CO-containing fuel stream (e.g., reformate gas) in the presence of catalyst within the fuel cell. In such methods, the concentration of oxygen introduced into the fuel stream is

selected to adequately react with CO so that it oxidizes to carbon dioxide, with CO typically being present at concentrations less than 100 ppm. However, the concentration of oxygen introduced into the fuel stream is also selected to avoid excess oxygen reacting with hydrogen in the fuel. Thus, such methods seek to avoid combusting fuel and oxidant within the fuel stream pathway, since this reduces fuel efficiency.

A method and apparatus for increasing the temperature of a fuel cell stack and/or for cold start-up of a fuel cell stack that is simple and efficient and that does not rely on external power sources is desired.

## SUMMARY OF THE INVENTION

The present method and apparatus provides for the combustion of fuel and oxidant within reactant or coolant pathways within the stack, thereby increasing the temperature of the stack on start-up or maintaining a desired operating temperature during operation, without requiring an external heating source, such as a storage battery. A method and apparatus for increasing the temperature of a solid polymer electrolyte fuel cell stack by combusting fuel and oxidant in the coolant or reactant pathways thereof is provided.

In one embodiment of a method for increasing the temperature of a solid polymer electrolyte fuel cell stack, the stack comprises a coolant pathway for directing a coolant fluid stream through the stack or through at least a portion of the stack, and the stack comprises at least one fuel cell.

The coolant pathway comprises at least one inlet, at least one outlet, and at least one passage fluidly interconnecting the inlet(s) and outlet(s). The at least one fuel cell comprises a membrane electrode assembly comprising an anode, a cathode, and an ion exchange membrane interposed therebetween. The at least one fuel cell further comprises a fuel stream passage for directing a fuel stream to the anode and an oxidant stream passage for directing an oxidant stream to the cathode, each of the streams being flowable to the fuel cell stack. The method comprises:

supplying at least a portion of each of the fuel and oxidant streams to the coolant pathway; and

combusting fuel and oxidant therein, such that the temperature of at least a portion of at least one membrane electrode assembly increases.

The coolant pathway may be fluidly isolated from each membrane electrode assembly in the stack and may further comprise catalyst disposed within at least a portion thereof for facilitating combustion of the fuel and the oxidant therein. Particularly, the catalyst may be disposed within at least a portion of one or more passages of the coolant pathway to which both of the fuel and oxidant streams are supplied.

The temperature of at least a portion of at least one membrane electrode assembly preferably increases to at least the minimum normal operating temperature of said fuel cell.

The method may further comprise interrupting the supplying of fuel and oxidant

streams to the coolant pathway and then directing coolant thereto.

The method typically further comprises purging coolant from the coolant pathway prior to or concurrent with supplying at least a portion of each of the fuel and oxidant streams to the coolant pathway. The purging may comprise directing a fluid stream through the coolant pathway. The fluid stream may be a gas stream, such as, for example, fuel, air, nitrogen, argon, helium, or carbon dioxide.

The present method may optionally further comprise:

monitoring at least one operating parameter of the stack indicative of the temperature of at least a portion of at least one membrane electrode assembly; and combusting fuel and oxidant in the coolant pathway at least until the operating parameter(s) indicates that the temperature of at least a portion of the membrane electrode assembly has increased to a first predetermined threshold.

The method may further comprise interrupting the supplying of both of the fuel and oxidant streams to the coolant pathway when the operating parameter(s) indicates that the temperature has exceeded the first threshold. The first threshold may be within the normal operating temperature range of the fuel cell or may be below that range, such as, for example, between about 20 °C and about 50 °C.

The method also may further comprise directing a coolant to the coolant pathway in response to the operating parameter(s). For example, coolant may be directed to the coolant

pathway when the operating parameter(s) indicates that the temperature has at least reached a second predetermined threshold, wherein the second predetermined threshold is the same or higher than the first predetermined threshold. The second threshold may be within the normal operating temperature range of the fuel cell or may be above that range.

In the present method, the stack may be connectable to an external electric circuit for supplying electric current to the circuit, and the method may further comprise simultaneously:

supplying a portion of the oxidant reactant stream to the cathode of at least one fuel cell of the stack, supplying a portion of the fuel reactant stream to the anode of at least one fuel cell of the stack, and

supplying electric current from the stack to the external circuit.

The stack may employ any conventional fuel stream, such as, for example, a fuel stream comprising hydrogen, reformate, methanol or dimethyl ether.

In alternative embodiments of the present method, the stack comprises at least one fuel cell comprising a membrane electrode assembly comprising an anode, a cathode, and an ion exchange membrane interposed therebetween. The at least one fuel cell further comprises at least one fuel stream passage for directing a fuel stream to the anode and at least one oxidant stream passage for directing an oxidant stream to the cathode, each of the streams being flowable to the fuel cell stack. The method comprises:

monitoring at least one operating parameter of the stack indicative of the temperature of at least a portion of at least one membrane electrode assembly; and supplying at least a portion of both of the fuel and oxidant streams to at least one of the reactant passages in response to the operating parameter(s) and combusting fuel and oxidant in at least one of the reactant passages such that the temperature of at least a portion of the membrane electrode assembly increases.

The stack may be connectable to an external circuit for supplying electric current to the external circuit, and the method may further comprise simultaneously:

supplying a portion of the oxidant reactant stream to the cathode of at least one fuel cell of the stack, supplying a portion of the fuel reactant stream to the anode of at least one fuel cell of the stack, and

supplying electric current from the stack to the external circuit.

The stack may employ any conventional fuel stream, such as, for example, a fuel stream comprising hydrogen, reformate, methanol or dimethyl ether.

Preferably both the fuel and oxidant streams are supplied to and combusted in at least one of the reactant passages when the operating parameter(s) indicates that the temperature is below a predetermined threshold. The method may further comprise interrupting the supplying of both of the fuel and oxidant streams to at least one of the reactant

passages when the operating parameter(s) indicates that the temperature has exceeded the threshold (although in most embodiments, supply of one reactant will continue). The threshold may be within the normal operating temperature range of the fuel cell or below that range, such as, for example, between about 20 °C and about 50 °C.

An embodiment of the present apparatus comprises a solid polymer electrolyte fuel cell stack comprising:

a coolant pathway for flowing a coolant fluid stream through the stack, comprising at least one inlet, at least one outlet, and at least one passage fluidly interconnecting the inlet(s) and the outlet(s);

at least one fuel cell comprising a membrane electrode assembly comprising an anode, a cathode, and an ion exchange membrane interposed therebetween, the at least one fuel cell further comprising a fuel stream passage for directing a fuel stream to the anode and an oxidant stream passage for directing an oxidant stream to the cathode, each of the streams being flowable to the fuel cell stack; and passages for selectively directing both the fuel stream and the oxidant stream to the coolant pathway.

The coolant pathway may be fluidly isolated from each of the membrane electrode assemblies in the stack.

The stack may further comprise a device for facilitating combustion of the fuel and the oxidant in the coolant pathway. The device may

comprise catalyst disposed within at least a portion of the coolant pathway, particularly within at least a portion of a passage of the coolant pathway. Alternatively, the device may comprise, for example, a heating coil, spark plug, ignition coil or laser diode.

The stack may further comprise a device for purging coolant from the coolant pathway. The stack may also further comprise one or more sensors for monitoring at least one operating parameter of the stack indicative of the temperature of at least a portion of the membrane electrode assembly, and a control system for controlling the flow of the fuel and oxidant to the coolant pathway in response to an output from the sensor(s). Optionally, the stack may also comprise a control system for directing the flow of the coolant to the coolant pathway in response to an output from the sensor(s).

The stack may be connectable to an external circuit for supplying electric current to the external circuit, and may further comprise a control system for controlling the supply of electric current from the stack to the external circuit.

In another embodiment of the present apparatus, the solid polymer electrolyte fuel cell stack comprises:

at least one fuel cell comprising a membrane electrode assembly comprising an anode, a cathode, and an ion exchange membrane interposed therebetween, a fuel stream passage for directing a fuel stream to the anode and an oxidant stream passage for directing an oxidant stream to the

cathode, each of the streams being flowable to the fuel cell stack;

at least one sensor for monitoring at least one operating parameter of the stack indicative of the temperature of at least a portion of the membrane electrode assembly; and

a control system for controlling the flow of both the fuel and oxidant streams to at least one of the reactant passages in response to an output from the sensor(s).

The stack may further comprise a device for facilitating combustion of the fuel and the oxidant in at least one of the passages. The device may comprise catalyst disposed within at least a portion of one of the passages. The device may also comprise, for example, a heating coil, spark plug, ignition coil or laser diode.

**BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1 is a schematic diagram of an embodiment of the present method and apparatus employing combustion of fuel and oxidant within a coolant pathway of a fuel cell stack.

FIG. 2 is a schematic diagram of another embodiment of the present method and apparatus employing combustion of fuel and oxidant within a coolant pathway of a fuel cell stack.

FIG. 3 is a schematic diagram of yet another embodiment of the present method and apparatus employing combustion of fuel and oxidant within a coolant pathway of a fuel cell stack.

FIG. 4 is a schematic diagram of another

embodiment of the present method and apparatus employing combustion of fuel and oxidant within a reactant pathway of a fuel cell stack.

## DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

As used in this description and in the appended claims, combustion includes reactions between a hydrogen-containing fuel and an oxygen-containing oxidant producing, among other things, carbon dioxide, water and heat (i.e. an exothermic process).

A conventional electrochemical fuel cell assembly typically includes a membrane electrode assembly interposed between a pair of substantially fluid impermeable plates. The membrane electrode assembly typically includes an ion exchange membrane interposed between two electrodes, namely, an anode and a cathode. In conventional fuel cells, the anode and cathode each include a layer of porous electrically conductive material such as, for example, carbon fiber paper or carbon cloth, which has electrocatalyst material associated therewith. Electrocatalyst material is commonly disposed in a thin layer on the surfaces of the electrodes at each electrode-membrane interface. The electrode may contain more than one type of electrocatalyst material, such as, for example, the electrode described in U.S. Pat. No. 5,795,669 which is incorporated by reference herein. The location of the electrocatalyst defines the electrochemically active area of the fuel cell assembly. The plates may each have at least one open-faced channel formed in the surfaces thereof facing

the membrane electrode assembly. Such plates are commonly referred to as fluid flow field plates. When assembled against the cooperating surfaces of the electrodes, the channels define reactant flow passages for fluid fuel and oxidant streams at the anode and cathode sides of the membrane electrode assembly, respectively. Alternatively, the plates may have substantially smooth surfaces and the porous electrically conductive material may have open-faced flow channels formed in the surfaces thereof facing the plates (or the flow passages may comprise the porous electrically conductive material itself). In these configurations, the plates are commonly referred to as separator plates. Fuel cell assemblies may also include coolant fluid flow field plates for the flow of coolant through coolant flow passages formed therein.

Bipolar fluid flow field plates typically have channels formed in both opposing planar surfaces and may be shared between two adjacent fuel cell assemblies. Bipolar plates may have fuel and oxidant flow channels formed in opposing surfaces, respectively, or may have fuel or oxidant flow channels formed in one surface and coolant channels formed in the other. Such coolant flow field plates are described, for example, in U.S. Pat. No. 5,230,966 which is incorporated by reference herein.

Alternatively, fuel cell assemblies may employ separator layers having reactant and coolant flow channels on both surfaces thereof, as described in U.S. Pat. No. 5,804,326 which is incorporated by reference herein. In this

arrangement the coolant flow channels do not superpose the electrochemically active area of the membrane electrode assembly, and the coolant is fluidly isolated from it. Other designs may have the coolant in fluid communication with the electrochemically active area of the adjacent membrane electrode assembly.

A plurality of fuel cell assemblies may be combined in series or in parallel to form a fuel cell stack. The stack may include external manifolds for supplying and exhausting reactants and coolant to and from the flow passages of the individual fluid flow field plates. Alternatively, the plates may have aligned openings extending through the thickness of the fuel cell assemblies to form internal manifolds for supplying and exhausting reactants and coolant. A fuel cell stack design employing such internal manifolds is described, for example, in U.S. Pat. No. 5,252,410 which is incorporated by reference herein. The stack may also employ a combination of internal and external manifolds.

A further alternative fuel cell stack design employs fluid flow field plates that do not have coolant flow channels formed therein. Instead, aligned openings extending through the thickness of the fuel cell assemblies form interconnected coolant passages through which a coolant stream is directed substantially perpendicular to the major planar surfaces of the stack assemblies. Thus, coolant stream passages extend through each fluid flow field plate, from a coolant stream inlet on one of its major surfaces to a coolant stream outlet

on the other major planar surface, and are disposed in the portion of the plate which does not superpose the electrochemically active area of the adjacent membrane electrode assembly. A stack of this design is described, for example, in FIG. 7 of U.S. Pat. No. 5,804,326, and supporting text.

Fuel cell stacks are used to supply electric power in power generation systems in various applications, such as, for example, stationary, portable, and motive applications, and the present method and apparatus can be used in connection with any of these applications. In the present method and apparatus, fuel and oxidant are combusted within coolant or reactant pathways of solid polymer electrolyte fuel cell electric power generation systems to increase the temperature of the fuel cells within the stack. The coolant and reactant pathways comprise the related flow passages of the individual fuel cell assemblies, stack manifolds, and system components for carrying the fluid streams to and from the stack. The present method and apparatus may be particularly useful in applications where the ambient temperature is below the normal operating temperature of the fuel cells and/or the system is subject to frequent shut-down and start-up cycles, and where the temperature of the fuel cells may fall below a desired temperature.

FIG. 1 is a schematic diagram of an embodiment of the present method and apparatus, comprising a fuel cell electric power generation system 100 including a fuel cell stack 110. Fuel cell stack 110 includes

negative and positive bus plates 112, 114, respectively, to which an external circuit comprising a variable load 116 is electrically connectable by closing switch 118. The system includes a fuel circuit, an oxidant circuit, and a coolant circuit. The reactant and coolant streams are circulated in the system in various conduits illustrated schematically in FIG. 1. In FIG. 1 and the following description, the fuel is hydrogen, the oxidant is air, and the coolant is water. These are non-limiting examples of fuels, oxidants, and coolants that may be used in the embodiment shown in FIG. 1.

A hydrogen supply 120, which supplies hydrogen at a pressure controlled by pressure regulator 121, is connected to stack 110. Water in the hydrogen stream exiting stack 110 is accumulated in a knockout drum 122, which can be drained by opening valve 123. Unreacted hydrogen is recirculated by a pump 124 in recirculation loop 125. An air supply 130, which supplies air at a pressure controlled by pressure regulator 131, is connected to stack 110. Water in the air stream exiting stack 110 is accumulated in reservoir 132, which can be drained by opening valve 133, and the air stream is vented from the system via valve 134.

In coolant circuit 140, water is pumped from reservoir 132 and circulated through stack 110 by pump 141. The temperature of the water is adjusted in a heat exchanger 142.

Hydrogen and air can be supplied to coolant circuit 140 and combusted within the coolant pathway in order to increase the temperature of stack 110. Hydrogen from

hydrogen supply 120 and air from air supply 130 are supplied to three-way valves 150 and 152, respectively. During normal operation of system 100, valves 150 and 152 direct the hydrogen and air streams to stack 110 via hydrogen and air conduits 154 and 156, respectively. Optionally, valves 150 and 152 may direct at least a portion of the hydrogen and air streams to valve 170 via conduits 162 and 164, respectively. Adjusting valve 170 permits a supply of fuel-oxidant mixture (in this case, hydrogen and air) to enter the coolant circuit and prevents coolant from flowing therethrough. Fuel-oxidant mixture supplied to coolant circuit is vented via valve 134. Preferably, pump 141 stops when valve 170 is adjusted to supply the fuel-oxidant mixture, in order to prevent pressure from building up within the portion of coolant circuit 140 upstream of valve 170.

The introduction of the fuel-oxidant mixture preferably purges coolant from the coolant pathways at least in fuel cell stack 110. An ignition device (not shown) facilitates the combustion of the fuel-oxidant mixture in the coolant pathway, preferably within stack 110. Purging of the coolant pathways within stack 110 may precede combustion, or may be concurrent therewith. Alternatively, where it is desired to purge the coolant pathways within stack 110 prior to combusting a fuel-oxidant mixture therein, either fuel or air alone (preferably air) may be used.

In certain applications, it may be desirable to purge the coolant pathways during

shut-down, for example, to prevent the coolant from freezing within the coolant pathways when the ambient temperature may fall below the freezing point of the coolant. Subsequently, on start-up in such cases, fuel and air can be supplied to coolant circuit 140 via valve 170, and the fuel-oxidant mixture combusted, preferably within stack 110, prior to flowing coolant through coolant circuit 140. In other words, in certain cold start-up applications, it may not be necessary to purge the coolant pathways with the fuel-oxidant mixture immediately prior to, or concurrent with, combustion.

When at least a portion of the fuel cell assemblies in stack 110 have reached the desired temperature, valve 170 is then adjusted to interrupt the supply of the fuel-oxidant mixture to coolant circuit 140 and to direct the flow of coolant therethrough.

FIG. 2 is a schematic diagram of another embodiment of the present method and apparatus, comprising a fuel cell electric power generation system 200 including a fuel cell stack 210. Fuel cell stack 210 includes negative and positive bus plates 212, 214, respectively, to which an external circuit comprising a variable load 216 is electrically connectable by closing switch 218. The system includes a fuel circuit, an oxidant circuit, and a coolant circuit. The reactant and coolant streams are circulated in the system in various conduits illustrated schematically in FIG. 2. In FIG. 2 and the following description, the fuel is hydrogen, the oxidant is air, and the coolant is water. These are

non-limiting examples of fuels, oxidants, and coolants that may be used in the embodiment shown in FIG. 2.

A hydrogen supply 220 is connected to stack 210, and the hydrogen pressure is controlled by pressure regulator 221. Water in the hydrogen stream exiting stack 210 is accumulated in a knockout drum 222, which can be drained by opening valve 223. Unreacted hydrogen is recirculated by a pump 224 in recirculation loop 225. An air supply 230, which supplies air at a pressure controlled by pressure regulator 231, is connected to stack 210. Water in the air stream exiting stack 210 is accumulated in reservoir 232, which can be drained by opening valve 233, and the air stream is vented from the system via valve 234.

In the coolant circuit 240, water is pumped from reservoir 232 and circulated through stack 210 by pump 241. The temperature of the water is adjusted in a heat exchanger 242.

A purge system 250 is used to purge coolant, preferably from at least the coolant pathways within stack 210, with gas. In the following description, the purge gas is nitrogen, which is a non-limiting example of a purge gas that may be used in the embodiment shown in FIG. 2. Pressure regulator 253 controls flow of gas from a purge gas supply 252 to valve 254. Valve 254 and three-way valve 260 control flow of purge gas to coolant circuit 240. Adjusting valve 260 to supply purge gas to coolant circuit 240 prevents coolant from flowing therethrough. Purge gas is vented via valve 234. Preferably, pump 241

stops when valve 260 is adjusted to supply purge gas, preventing pressure from building up within the portion of coolant circuit 240 upstream of valve 260. Although nitrogen is specifically described, any suitable gas may be used in purge system 250, such as, for example, fuel gas, air, helium, argon, or carbon dioxide. The choice of gas may be determined at least in part by the specifics of system construction and operation. For example, system 200 may include fuel and/or oxygen enrichment components upstream of stack 210. Means for fuel and/or oxygen enrichment are known and include, for example, pressure swing adsorption apparatus or gas separation membranes. Such systems may generate substantially pure carbon dioxide during enrichment and may also provide a suitable purge gas source (which may be similar to the purge system illustrated in FIG. 3, for example). As a further example, air from air supply 230 could be used as a purge gas source.

Fuel and air can be supplied to coolant circuit 240 and combusted within the coolant pathway in order to increase the temperature of stack 210. In FIG. 2, hydrogen from hydrogen supply 220 and air from air supply 230 are supplied to three-way valves 270 and 272, respectively. During normal operation of system 200, valves 270 and 272 direct the flow of hydrogen and air to stack 210 via hydrogen and air conduits 274 and 276, respectively. Optionally, valves 270 and 272 may direct at least a portion of the hydrogen and air streams to conduits 278 and 280, respectively. Hydrogen and air in conduits 278 and 280 mix

and enter coolant circuit 240 at junction 282. An ignition device (not shown) facilitates the combustion of the fuel-oxidant mixture in the coolant pathway, preferably within stack 210. Combustion exhaust is vented via valve 234.

Where coolant is present in the coolant pathways of stack 210, nitrogen from purge gas supply 252 is supplied to coolant circuit 240 by opening valves 254 and adjusting valve 260, and coolant is purged from at least the coolant pathways within stack 210. Closing valve 254 then interrupts the nitrogen supply. In certain applications such as, for example, cold start-up, the coolant pathways within stack 210 may already have been purged of coolant. In these applications, valve 260 in coolant circuit 240 may be adjusted to prevent the flow of coolant through coolant circuit 240, but without supplying nitrogen thereto. In either case, hydrogen and air from conduits 278 and 280 can be then be supplied to coolant circuit 240 and combusted in the coolant pathway, preferably within stack 210.

When at least a portion of the fuel cell assemblies of stack 210 have reached the desired temperature, valve 260 is then adjusted to interrupt the supply of the fuel-oxidant mixture to coolant circuit 240 and to direct the flow of coolant therethrough. Valves 270 and 272 may direct the flow of reactants to stack 210 at the same time, or prior to adjusting valve 260.

In the fuel cell power generation systems illustrated in FIGS. 1 and 2, any suitable solid polymer electrolyte fuel cell stack may be employed, such as, for example, the stacks

discussed above. Although hydrogen and air are the fuel and oxidant illustrated in FIGS. 1 and 2, other fuels and oxidants are also suitable. For example, the illustrated systems may optionally include a catalytic reformer for converting a raw fuel stream, comprising, for example, natural gas, ethane, butane, light distillates, methanol, propane, naptha, kerosene, and/or combinations thereof, and water vapor into a hydrogen-rich reformate stream suitable for use as a fuel in the stack. In such systems, either the raw fuel or the reformate stream may be suitably mixed with oxidant and combusted within the coolant pathway. Alternatively, methane, for example, may be used directly as a fuel. Other suitable oxidants include, for example, substantially pure oxygen or oxygen mixed with an inert carrier gas (e.g., nitrogen). Also, while water is the illustrated coolant, other suitable coolant fluids may also be used, such as, for example, air or ethylene glycol, provided they are compatible with the particular system (see further discussion below).

FIG. 3 is a schematic diagram of yet another embodiment of the present method and apparatus, comprising a fuel cell electric power generation system 300 including a liquid feed fuel cell stack 310. Liquid feed fuel cells are known and any suitable stack comprising such fuel cells may be used. Fuel cell stack 310 includes negative and positive bus plates 312, 314, respectively, to which an external circuit comprising a variable load 316 is electrically connectable by closing switch

318. The system includes a fuel circuit, an oxidant circuit, and a coolant circuit. The reactant and coolant streams are circulated in the system in various conduits illustrated schematically in FIG. 3. In FIG. 3 and the following description, the fuel is aqueous methanol, the oxidant is air, and the coolant is water. These are non-limiting examples of fuels, oxidants, and coolants that may be used in the embodiment shown in FIG. 3.

The fuel stream is an aqueous methanol mixture derived from a methanol/water supply 320, a methanol supply 322, and a recirculated aqueous methanol mixture from conduit 324. Methanol/water supply 320 is provided at a desired concentration for fuel cell operation. Other arrangements may be preferable depending on the specifics of system construction and operation.

Pressure regulators 321 and 323 control the pressure of fluids supplied by aqueous methanol supply 320 and methanol supply 322, respectively. Fluids from each of aqueous methanol supply 320, methanol supply 322, and conduit 324 are supplied to mixing apparatus 328 in which the fluids are combined to form an appropriate fuel stream.

The fuel stream is supplied to stack 310 via conduit 330 and the excess is then discharged to separator 332 where carbon dioxide reaction product may be separated from unreacted methanol and water in the fuel stream exhaust. Carbon dioxide may then be vented via valve 335, while a pump 336 may recirculate the unreacted methanol/water mixture to conduit 324. A heat exchanger 338 may be employed to

adjust the temperature of some or all of the recirculating fluid stream.

The oxidant stream in FIG. 3 is provided by a compressed air supply 340, the pressure of which is controlled by pressure regulator 341, and flows to stack 310 via conduit 342. Water in the air stream exiting stack 310 is accumulated in reservoir 344, which can be drained by opening valve 345. The air stream is vented from the system via valve 346. The oxidant conduit may also include a condenser disposed between stack 310 and reservoir 344 to separate from the exhaust stream any unreacted methanol that may be present therein due to cross-over.

In coolant circuit 350, water is pumped from reservoir 344 and circulated through stack 310 by pump 351. The temperature of the water is adjusted in a heat exchanger 352.

A purge system 360 is used to purge coolant, preferably from at least the coolant pathways within stack 310, with gas. Pressure regulator 362 controls flow of carbon dioxide from separator 332 to valve 364. Flow of carbon dioxide to coolant circuit 350 is controlled by three-way valve 370. Adjusting valve 370 to prevent coolant from flowing through coolant circuit 350 may permit supply of carbon dioxide thereto. Carbon dioxide introduced into coolant circuit 350 is vented via valve 346. Preferably, pump 351 stops when valve 370 is adjusted, to prevent pressure from building up within the portion of coolant pathway 340 upstream of valve 370. In certain applications such as, for example, cold start-up, the coolant pathways within stack 310 may

already have been purged of coolant. In these applications, valve 370 may be adjusted to prevent the flow of coolant through coolant circuit 350, but without supplying carbon dioxide thereto.

Methanol and air can be supplied to coolant circuit 350 and combusted therein in order to increase the temperature of stack 310. Methanol from methanol supply 322 and air from air supply 340 are supplied to three-way valves 380 and 382, respectively. During normal operation of system 300, valve 380 directs methanol to mixing apparatus 328, as required, and valve 382 directs air to stack 310. Optionally, valves 380 and 382 may direct at least a portion of the methanol and air streams to conduits 384 and 386, respectively. Methanol and air in conduits 384 and 386 mix and enter coolant circuit 350 at junction 388. An ignition device (not shown) facilitates the combustion of the fuel-oxidant mixture, preferably within stack 310. Where coolant is present in the coolant pathways within stack 310, carbon dioxide from separator 332 is supplied to coolant circuit 350 by opening valve 364 and adjusting 370, and coolant is purged from at least the coolant pathway within stack 310. The carbon dioxide supply can then be interrupted by closing valve 364, and methanol and air from conduits 384 and 386 supplied to coolant circuit 350 and combusted therein, preferably within stack 310. Combustion exhaust is vented via valve 346.

When at least a portion of the fuel cell assemblies in stack 310 have reached the desired temperature, valve 370 is then adjusted

to interrupt the supply of the fuel-oxidant mixture to coolant circuit 350 and to direct the flow of coolant therethrough. Valves 380 and 382 may direct the flow of methanol to mixing apparatus 328, as required, and the flow of air to stack 310, respectively, at the same time valve 370 is closed, or prior to adjusting valve 370.

Although aqueous methanol and air are the fuel and oxidant illustrated in FIG. 3, other fuels and oxidants may also be suitable. For example, in PCT/International Publication No. WO 96/12317 (Application No. PCT/US94/11911) which is incorporated by reference herein, alternative liquid fuels, including aqueous solutions of dimethoxymethane (DMM), trimethoxymethane (TMM), and trioxane are suggested for direct use in liquid feed solid polymer electrolyte fuel cells. Alternatively, aqueous solutions of other low molecular weight alcohols, formic acid or dimethyl ether (DME), for example, may also be suitable for use as a fuel in such fuel cells.

Other suitable oxidants include, for example, substantially pure oxygen or oxygen mixed with an inert carrier gas (e.g., nitrogen). The oxidant may also be supplied as a liquid, for example, as a hydrogen peroxide solution or as an organic fluid with a high oxygen concentration, as described in U.S. Pat. No. 5,185,218 which is incorporated by reference herein. However, if a liquid oxidant is selected it is preferable that it be capable of mixing with the fuel and combusting within the coolant pathways of the stack. Alternatively, system 300 may further include a

means for supplying air to the coolant pathways for combustion purposes, such as a compressed air source or a compressor, or the like.

Also, any suitable coolant fluids may also be used in system 300, such as, for example, air, water or ethylene glycol, provided they are compatible.

Of course, the specific configuration of system 300 may vary according to various operating parameters. For example, additional components may be added to the system in order to acidify the fuel stream, if desired. As a further example, where methanol or DME is used as a fuel, a recirculation loop for the recovery of unreacted fuel in the oxidant exhaust may be included, as described in PCT/International Publication No. WO 99/44253 (Application No. PCT/CA99/00134) which is incorporated by reference herein.

In the fuel cell power generation systems illustrated in FIGS. 1-3, other conduit and/or valving configurations may be suitable, depending on the application, provided that at least a portion of the fuel and oxidant streams can be diverted to the coolant pathway. For example, the aqueous methanol mixture could be mixed with air and combusted in the coolant pathway, provided the methanol concentration is sufficient to support combustion. The device for facilitating combustion of the fuel-oxidant mixture can be any conventional device, such as, for example, a heating coil, spark plug, ignition coil or laser diode. Alternatively, the device may comprise a catalyst disposed within a portion of the coolant pathway. The catalyst may comprise conventional catalysts

including, for example, noble group metals (e.g., platinum, rhodium, palladium, ruthenium, osmium or iridium), gold or silver, non-noble metals (e.g., iron, chromium, cobalt or nickel), oxides or alloys of the foregoing, iron and cobalt macrocycles, and perovskites. The catalysts may be supported (e.g., supported on carbon) or unsupported. Preferably, the device is located in a portion of the coolant pathway immediately upstream of the stack, since this arrangement may provide for more efficient heat transfer to the stack and greater rate of temperature increase than placing the device downstream of the stack. More preferably, the device is disposed in the portion of the coolant pathway located within the stack itself, such as within the coolant inlet manifold, the coolant flow passages of at least one of the fuel cell assemblies.

In the fuel cell generation systems illustrated in FIGS. 1-3, the choice of coolant is also a factor to be considered in system design. Combustion of the fuel-oxidant mixture within the coolant pathway will produce water therein ("product water"). Preferably, the coolant is compatible with product water which may be generated within the coolant pathway. In this context, compatible means that either the product water can be separated from the coolant relatively easily, or the product water does not dilute or contaminate the coolant. For example, air and water are compatible. Alternatively, a liquid coolant immiscible with water may be chosen, since the product water may be removed from the coolant by phase separation, for example. If a water miscible

liquid coolant is chosen, however, it may be desirable, for example, to purge the coolant pathway after combusting the fuel-oxidant mixture therein so as to remove any accumulated product water prior to circulating therethrough.

Optionally, any of the fuel cell power generation systems illustrated in FIGS. 1-3 may further include at least one sensor for monitoring at least one operating parameter of the stack indicative of the temperature of at least a portion of one or more of the membrane electrode assemblies thereof and a control system for supplying fuel and oxidant to the coolant pathway responsive to the output of the sensor(s). Any suitable sensors may be employed, such as, for example, temperature sensors. Preferably, the sensor(s) are disposed within the stack itself. The control system may desirably control the flow of coolant within the coolant pathway and the supply of fuel and oxidant to it, in response to the output from the sensor(s). The control system may also control the device for facilitating the combustion of the fuel-oxidant mixture in the coolant pathway.

During operation, for example, the control system may interrupt the flow of coolant in the coolant pathway and supply fuel and oxidant to the coolant pathway in response to output from the sensor(s) indicating that the temperature in the stack has fallen below a predetermined threshold. Fuel and oxidant can then be combusted within the coolant pathway until the output from the sensor(s) indicates that the temperature in the stack has reached or

exceeded another predetermined threshold. The supply of fuel and oxidant may then be interrupted and the flow of coolant within the coolant pathway resumed. Alternatively, the supply of fuel and oxidant may be interrupted but the control system may delay resuming coolant flow within the coolant pathway until the output from the sensor(s) indicates that the monitored temperature has reached or exceeded a second predetermined threshold higher than the first predetermined threshold. The second predetermined threshold may be within the normal operating temperature range of the fuel cells or may be above that range, if desired. During cold start-up applications where the coolant pathways have been at least partially purged of coolant, the control system may operate in a similar manner, except that it may be unnecessary to interrupt the flow of coolant in the coolant pathway as a first step.

FIG. 4 is a schematic diagram of yet another embodiment of the present method and apparatus, comprising a fuel cell electric power generation system 400 including a fuel cell stack 410. Fuel cell stack 410 includes negative and positive bus plates 412, 414, respectively, to which an external circuit comprising a variable load 416 is electrically connectable by closing switch 418. The system includes a fuel circuit and an oxidant circuit. In FIG. 4 and the following description, the fuel is hydrogen and the oxidant is air. These are non-limiting examples of fuels and oxidants that may be used in the embodiment shown in FIG. 4. The reactant streams are circulated in the system in various conduits illustrated

schematically in FIG. 4. System 400 also includes at least one sensor 440 for monitoring at least one operating parameter of the stack indicative of the temperature of at least a portion of at least one membrane electrode assembly and a control system 445 for supplying fuel to the oxidant circuit responsive to the output of the sensor.

A hydrogen supply 420 is connected to stack 410, and the hydrogen pressure controlled by pressure regulator 421. Water in the hydrogen stream exiting the stack 410 is accumulated in a knockout drum 422, which can be drained by opening valve 423. Unreacted hydrogen is recirculated to stack 410 by a pump 424 in recirculation loop 425. An air supply 430, which supplies air at a pressure controlled by pressure regulator 431, is connected to stack 410. The air stream is vented from the system via valve 434.

Fuel from hydrogen supply 420 is supplied to three-way valve 450. During normal operation, valve 450 directs hydrogen from hydrogen supply 420 to stack 410 via conduit 452. Optionally, valve 450 may direct at least a portion of the hydrogen stream to conduit 454 via junction 456, where it mixes with air supplied to stack 410 from air supply 430. An ignition device (not shown) facilitates the combustion of the fuel-oxidant mixture in the oxidant pathway, preferably within stack 410, in order to increase the temperature thereof. Controller 445 adjusts valve 450 in response to output from sensor 440.

The device for facilitating combustion of the fuel-oxidant mixture can be any

conventional device previously discussed and may comprise a catalyst disposed within a portion of the oxidant pathway. In the latter case, the device may consist of or include the cathode electrocatalyst present in the membrane electrode assemblies of the fuel cells. For the reasons discussed above, the device is preferably located in a portion of the oxidant circuit immediately upstream of the stack, more preferably within the stack itself. Disposition of the device within at least a portion of the inlet manifold or within the membrane electrode assemblies is more preferred.

During operation, for example, controller 445 could initiate supply of fuel to conduit 454 in response to output from sensor 440 indicating that the temperature in the stack is at or below a predetermined threshold. Fuel and oxidant can then be combusted within the oxidant pathway, preferably within the portion thereof disposed within the stack, until the output from sensor 440 indicates that the monitored temperature has reached or exceeded a predetermined threshold. The supply of fuel to the oxidant circuit may then be interrupted and normal operation started or resumed.

Any suitable solid polymer electrolyte fuel cell stack configuration may be employed in system 400 of FIG. 4, including liquid feed solid polymer electrolyte fuel cell stacks. For example, a portion of the methanol stream of a liquid feed fuel cell system could be diverted to the oxidant circuit for combusting a fuel-oxidant mixture therein. Where the fuel is other than substantially pure hydrogen,

however, the fuel stream is preferably substantially pure and relatively free of electrocatalyst "poisons", or the fuel cell design is preferably suitably resistant to poisoning. As another example, instead of diverting a portion of the fuel stream to the oxidant circuit, as illustrated in FIG. 4, a portion of the oxidant stream may be diverted to the fuel circuit, if desired. Other system configurations may also be suitable, depending on the desired application and system specifications, provided that at least a portion of one reactant stream can be diverted to the other reactant circuit and the resulting fuel-oxidant mixture is capable of being combusted therein.

Preferably, in the present method and apparatus, the portion of the reactant stream(s) to be diverted for combustion purposes can be variably controlled. By diverting only a portion of the reactant stream(s) it may be possible to supply the stack with sufficient reactants to maintain electric power generation during the combustion process. Thus, it may be possible to increase the temperature of the stack during operation thereof if the temperature is undesirably low. However, if desired, substantially all of the reactant stream may be diverted for combustion purposes in cold start-up applications. This may increase the rate at which the temperature of the stack increases and thereby shorten the time required before it reaches a desired operating temperature. Alternatively, the portion of reactants diverted for such purposes may be varied over time to allow concurrent

electric power generation in the stack before an optimal operating temperature is reached.

While particular elements, embodiments and applications of the present invention have been shown and described, it will be understood, of course, that the invention is not limited thereto since modifications may be made by those skilled in the art in light of the foregoing teachings. It is therefore contemplated by the appended claims to cover such modifications that incorporate those features coming within the spirit and scope of the invention.

What is claimed is:

1. A method of increasing the temperature of a solid polymer electrolyte fuel cell stack, said stack comprising,

a coolant pathway for directing a coolant fluid stream through at least a portion of said stack, said coolant pathway comprising at least one inlet, at least one outlet, and at least one passage fluidly interconnecting said at least one inlet and said at least one outlet, and

at least one fuel cell comprising a membrane electrode assembly comprising an anode, a cathode, and an ion exchange membrane interposed therebetween, said at least one fuel cell further comprising a fuel stream passage for directing a fuel stream to said anode and an oxidant stream passage for directing an oxidant stream to said cathode, each of said streams being flowable to said fuel cell stack,

the method comprising:
(a) supplying at least a portion of each of fuel and oxidant streams to said coolant pathway; and
(b) combusting fuel and oxidant therein, such that the temperature of at least a portion of at least one said membrane electrode assembly increases.

2. The method of claim 1, wherein said coolant pathway further comprises catalyst

disposed within at least a portion thereof for facilitating combustion of said fuel and said oxidant in said coolant pathway.

3. The method of claim 2, wherein said catalyst is disposed within at least a portion of said at least one passage of said coolant pathway.

4. The method of claim 1, wherein said coolant pathway is fluidly isolated from each membrane electrode assembly in said stack.

5. The method of claim 1, wherein the temperature of said at least a portion of at least one said membrane electrode assembly increases to at least the minimum normal operating temperature of said fuel cell.

6. The method of claim 1, further comprising:
(c) interrupting the supplying of said fuel and said oxidant to said coolant pathway; and
(d) directing a coolant to said coolant pathway.

7. The method of claim 1, further comprising: monitoring at least one operating parameter of said stack indicative of the temperature of said at least a portion of at least one said membrane electrode assembly; and combusting fuel and oxidant in said coolant pathway at least until said operating parameter indicates that

the temperature of at least one said at least a portion of said membrane electrode assembly has increased to a first predetermined threshold.

8. The method of claim 7, wherein said first threshold is within the normal operating temperature range of said fuel cell.

9. The method of claim 7, further comprising: interrupting the supplying of said fuel and oxidant streams to said coolant pathway when said at least one operating parameter indicates that said temperature has exceeded said first threshold.

10. The method of claim 9, wherein said first threshold is 20 °C.

11. The method of claim 9, wherein said first threshold is 30 °C.

12. The method of claim 9, wherein said first threshold is 40 °C.

13. The method of claim 9, wherein said first threshold is 50 °C.

14. The method of claim 9, further comprising: directing a coolant to said coolant pathway in response to said at least one operating parameter.

15. The method of claim 14, wherein said method comprises directing said coolant to said coolant pathway in response to said

at least one operating parameter when said at least one operating parameter indicates that said temperature has at least reached a second predetermined threshold, wherein said second predetermined threshold is not less than said first predetermined threshold.

16. The method of claim 15, wherein said second threshold is within the normal operating temperature range of said fuel cell.

17. The method of claim 15, wherein said second threshold is above the normal operating temperature range of said fuel cell.

18. The method of claim 15, wherein said second threshold is greater than said first threshold.

19. The method of claim 1, wherein step (a) further comprises purging a coolant from said coolant pathway.

20. The method of claim 1, wherein a coolant is purged from said coolant pathway prior to step (a).

21. The method of claim 20, wherein said purging comprises directing a fluid stream through said coolant pathway.

22. The method of claim 21, wherein said fluid stream is a gas stream.

23. The method of claim 22, wherein said gas stream is selected from the group consisting of fuel, air, nitrogen, argon, helium, and carbon dioxide.

24. The method of claim 22, wherein said gas stream is nitrogen.

25. The method of claim 22, wherein said gas stream is carbon dioxide.

26. The method of claim 1, wherein said fuel stream comprises a fuel selected from the group consisting of hydrogen, methanol and dimethyl ether.

27. The method of claim 1, wherein said stack is connectable to an external electric circuit for supplying electric current to said circuit, said method further comprises, simultaneously with steps (a) and (b):
supplying a portion of said oxidant reactant stream to said cathode of said at least one fuel cell, supplying a portion of said fuel reactant stream to said anode of said at least one fuel cell, and supplying electric current from said stack to said external circuit.

28. A solid polymer electrolyte fuel cell stack comprising:
(a) a coolant pathway for flowing a coolant fluid stream through at least a portion of said stack, said coolant

pathway comprising at least one inlet, at least one outlet, and at least one passage fluidly interconnecting said at least one inlet and said at least one outlet;

(b) at least one fuel cell comprising a membrane electrode assembly comprising an anode, a cathode, and an ion exchange membrane interposed therebetween, said at least one fuel cell further comprising a fuel stream passage for directing a fuel stream to said anode and an oxidant stream passage for directing an oxidant stream to said cathode, each of said streams being flowable to said fuel cell stack; and

(c) passages for selectively directing both of said fuel stream and said oxidant stream to said coolant pathway.

29. The stack of claim 28, further comprising a device for facilitating combustion of fuel and oxidant in said coolant pathway.

30. The stack of claim 29, wherein said device comprises catalyst disposed within at least a portion of said coolant pathway.

31. The stack of claim 30, wherein said catalyst is disposed within at least a portion of said at least one passage of said coolant pathway.

32. The stack of claim 29, wherein said device

is selected from the group comprising a heating coil, spark plug, ignition coil and laser diode.

33. The stack of claim 29, wherein said coolant pathway is fluidly isolated from each membrane electrode assembly in said stack.

34. The stack of claim 29, further comprising a device for purging a coolant from said coolant pathway.

35. The stack of claim 29, further comprising:
(d) at least one sensor for monitoring at least one operating parameter of said stack indicative of the temperature of said at least a portion of at least one said membrane electrode assembly;
(e) a control system for controlling the flow of both of said fuel and oxidant streams to said coolant pathway in response to an output from said at least one sensor.

36. The stack of claim 35, further comprising: a control system for directing the flow of
(f) a coolant to said coolant pathway in response to an output from said at least one sensor.

37. The stack of claim 29, wherein said stack is connectable to an external circuit for supplying electric current to said external circuit, and wherein said stack

further comprises a control system for supplying electric current from said stack to said external circuit.

38. A solid polymer electrolyte fuel cell stack comprising:

(a) a coolant pathway for flowing a coolant fluid stream through at least a portion of said stack, said coolant pathway comprising at least one inlet, at least one outlet, and at least one passage fluidly interconnecting said at least one inlet and said at least one outlet;

(b) at least one fuel cell comprising a membrane electrode assembly comprising an anode, a cathode, and an ion exchange membrane interposed therebetween, said at least one fuel cell further comprising means for directing a fuel stream to said anode and means for directing an oxidant stream to said cathode, each of said streams being flowable to said fuel cell stack; and

(c) means for directing said fuel stream and said oxidant stream to said coolant pathway.

39. The stack of claim 38, further comprising means for facilitating combustion of fuel and oxidant in said coolant pathway.

40. The stack of claim 38, further comprising means for purging a coolant from said coolant pathway.

41. The stack of claim 38, further comprising:
    (d) sensing means for monitoring at least one operating parameter of said stack indicative of the temperature of at least a portion of at least one said membrane electrode assembly;
    (e) means for controlling the flow of said fuel and oxidant streams to said coolant pathway in response to said sensing means.

42. The stack of claim 38, further comprising:
    (d) sensing means for monitoring at least one operating parameter of said stack indicative of the temperature of said at least a portion of at least one said membrane electrode assembly;
    (e) means for directing the flow of a coolant to said coolant pathway in response to said sensing means.

43. The stack of claim 38, wherein said stack is connectable to an external circuit for supplying electric current to said external circuit, further comprising means for supplying electric current from said stack to said external circuit.

44. A method of increasing the temperature of a solid polymer electrolyte fuel cell stack, said stack comprising at least one fuel cell comprising a membrane electrode assembly comprising an anode, a cathode, and an ion exchange membrane interposed therebetween, said at least one fuel cell

further comprising at least one fuel stream passage for directing a fuel stream to said anode and at least one oxidant stream passage for directing an oxidant stream to said cathode, each of said streams being flowable to said fuel cell stack, the method comprising:

(a) monitoring at least one operating parameter of said stack indicative of the temperature of at least a portion of at least one said membrane electrode assembly; and

(b) supplying at least a portion of both of said fuel and oxidant streams to at least one of said passages in response to said at least one operating parameter and combusting fuel and oxidant in at least one of said passages such that the temperature of at least a portion of at least one said membrane electrode assembly increases.

45. The method of claim 44, wherein said stack is connectable to an external circuit for supplying electric current to said external circuit, said method further comprises, simultaneously with steps (a) and (b):

supplying a portion of said oxidant stream to said cathode of said at least one fuel cell, supplying a portion of said fuel stream to said anode of said at least one fuel cell, and

supplying electric current from said stack to said external circuit.

46. The method of claim 44, wherein both of said fuel and oxidant streams are supplied to and combusted in said at least one of said passages when the monitored operating parameter indicates that said temperature is below a predetermined threshold.

47. The method of claim 44, wherein said threshold is within the normal operating temperature range of said fuel cell.

48. The method of claim 44, further comprising:
   (c) interrupting the supplying of both of said fuel and oxidant streams to said at least one of said passages when the monitored operating parameter indicates that the temperature has exceeded a threshold.

49. The method of claim 48, wherein the threshold is 20 °C.

50. The method of claim 48, wherein the threshold is 30 °C.

51. The method of claim 48, wherein the threshold is 40 °C.

52. The method of claim 48, wherein the threshold is 50 °C.

53. The method of claim 44, wherein said fuel stream comprises a fuel selected from the group consisting of hydrogen, methanol and dimethyl ether.

54. A solid polymer electrolyte fuel cell stack comprising:
   (a) at least one fuel cell, said at least one fuel cell comprising a membrane electrode assembly comprising an anode, a cathode, and an ion exchange membrane interposed therebetween, at least one fuel stream passage for directing a fuel stream to said anode and at least one oxidant stream passage for directing an oxidant stream to said cathode, each of said streams being flowable to said fuel cell stack;
   (b) at least one sensor for monitoring at least one operating parameter of said stack indicative of the temperature of at least a portion of at least one said membrane electrode assembly; and
   (c) a control system for controlling the flow of both of said fuel and oxidant streams to at least one of said passages in response to an output from said at least one sensor.

55. The stack of claim 54, further comprising:
   (d) a device for facilitating combustion of fuel and oxidant in said at least one of said passages.

56. The stack of claim 54, wherein said device comprises catalyst disposed within at least a portion of at least one passage.

57. The stack of claim 55, wherein said device

is selected from the group consisting of a heating coil, spark plug, ignition coil and laser diode.

58. A solid polymer electrolyte fuel cell stack comprising:

(a) at least one fuel cell, said at least one fuel cell comprising a membrane electrode assembly comprising an anode, a cathode, and an ion exchange membrane interposed therebetween, at least one fuel stream passage for directing a fuel stream to said anode and at least one oxidant stream passage for directing an oxidant stream to said cathode, each of said streams being flowable to said fuel cell stack;

(b) sensing means for monitoring at least one operating parameter of said stack indicative of the temperature of at least a portion of at least one said membrane electrode assembly; and

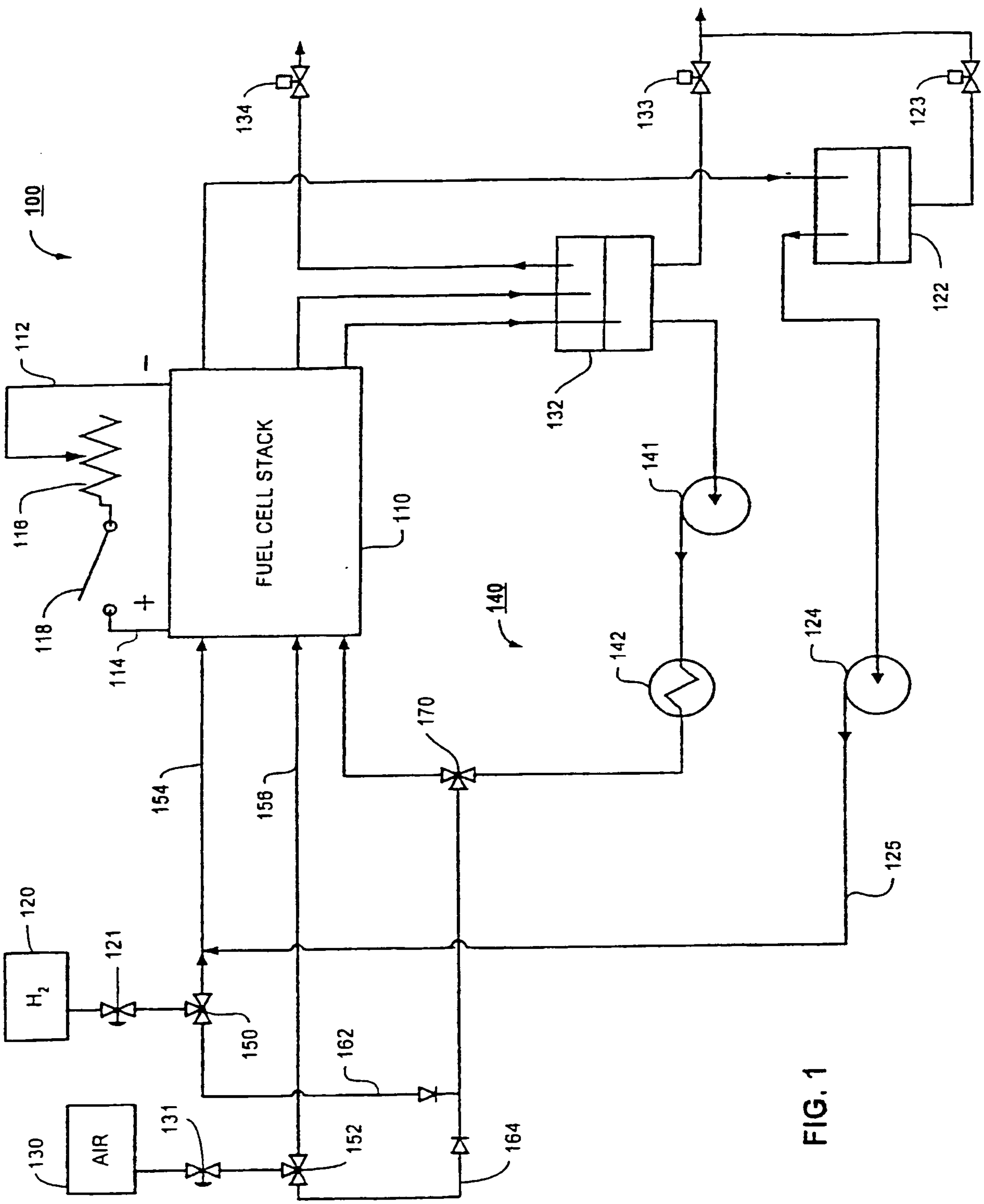
(c) means for controlling the flow of both of said fuel and oxidant streams to at least one of said passages in response to said sensing means.

59. The stack of claim 58, further comprising:

(d) means for facilitating combustion of fuel and oxidant within said at least one of said passages.

60. The stack of claim 58, wherein said stack is connectable to an external circuit for supplying electric current to said

external circuit, further comprising means for supplying electric current from said stack to said external circuit.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164
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FIG. 1

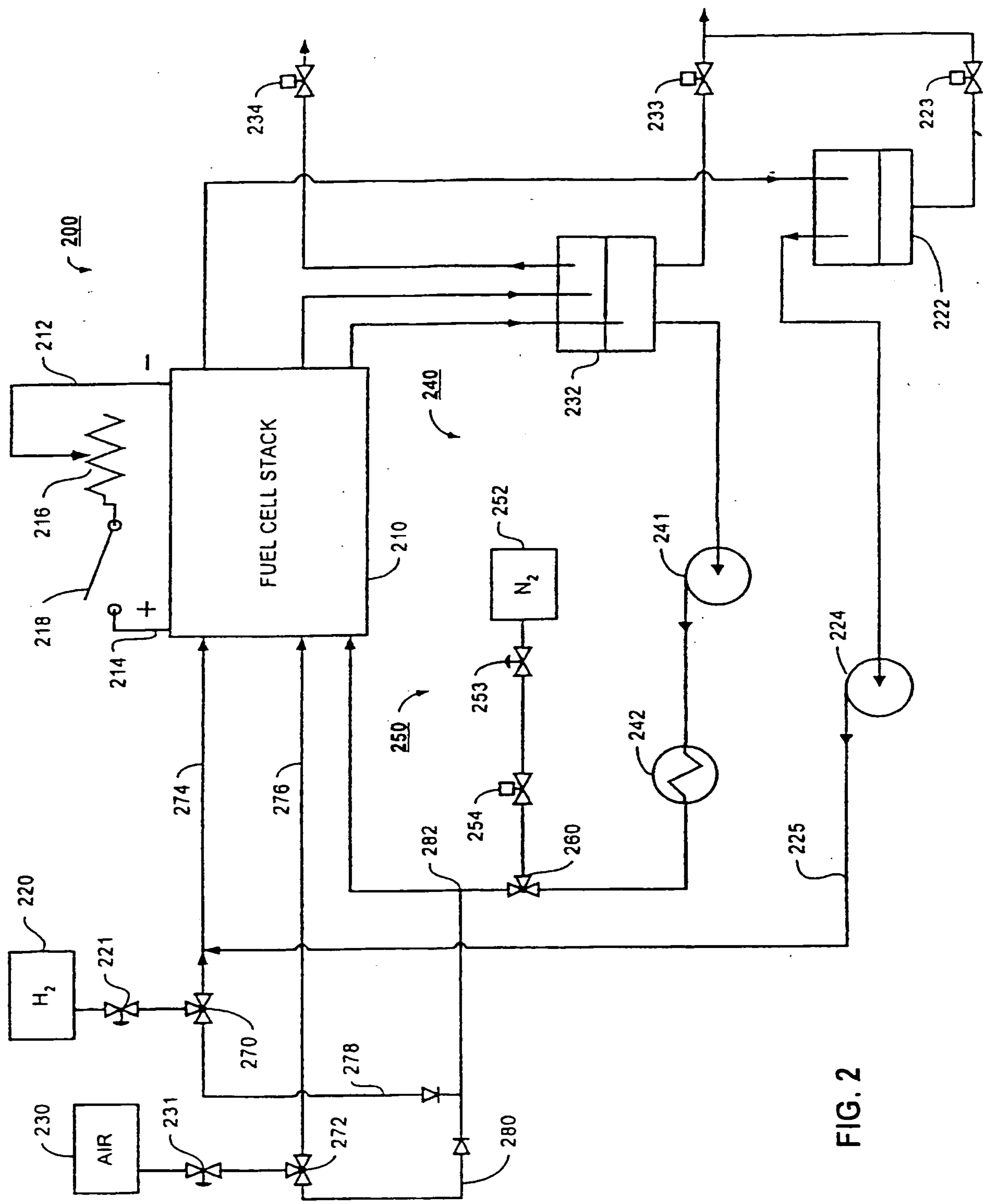
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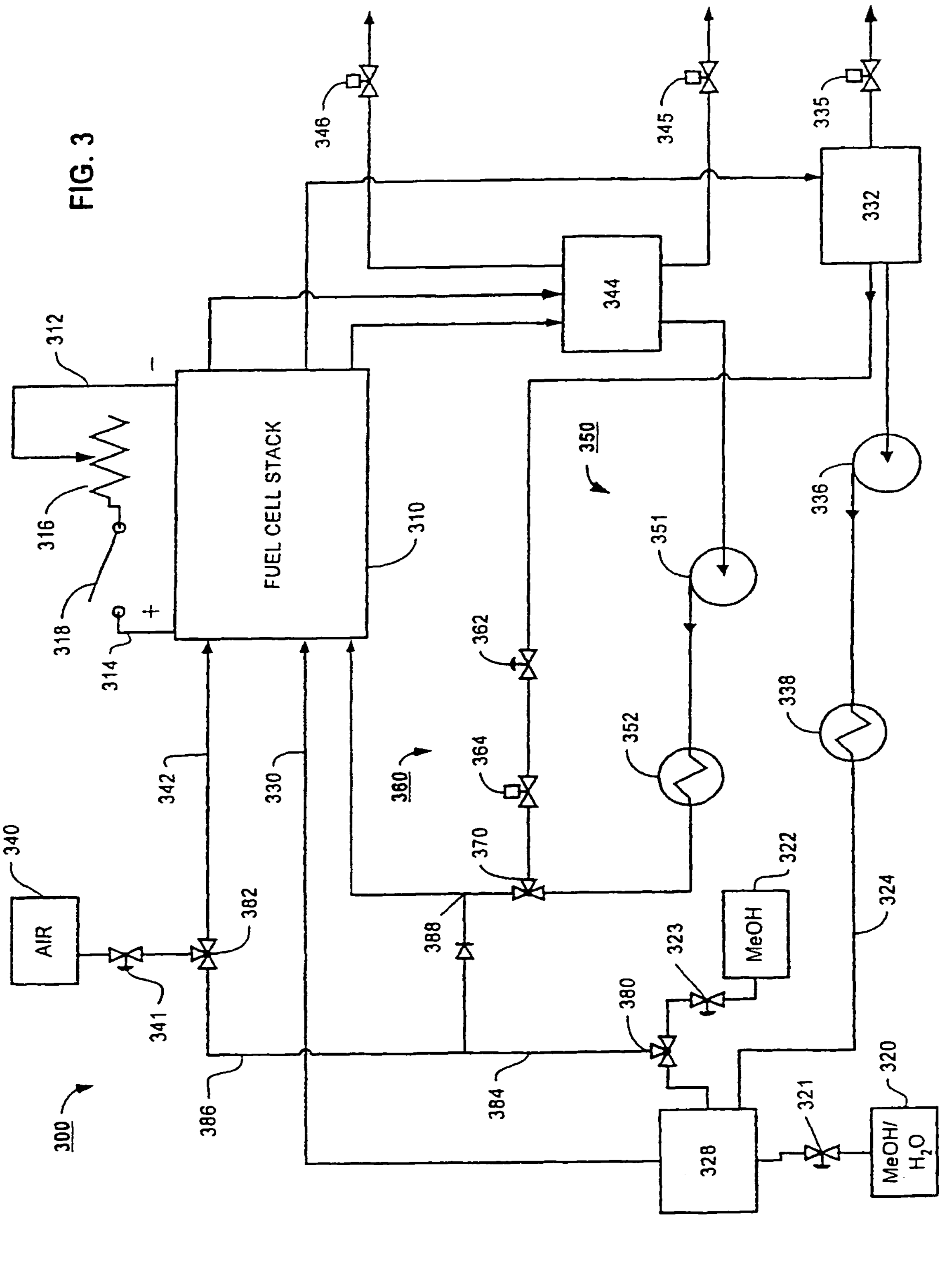
FIG. 2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335
336
338
340
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+
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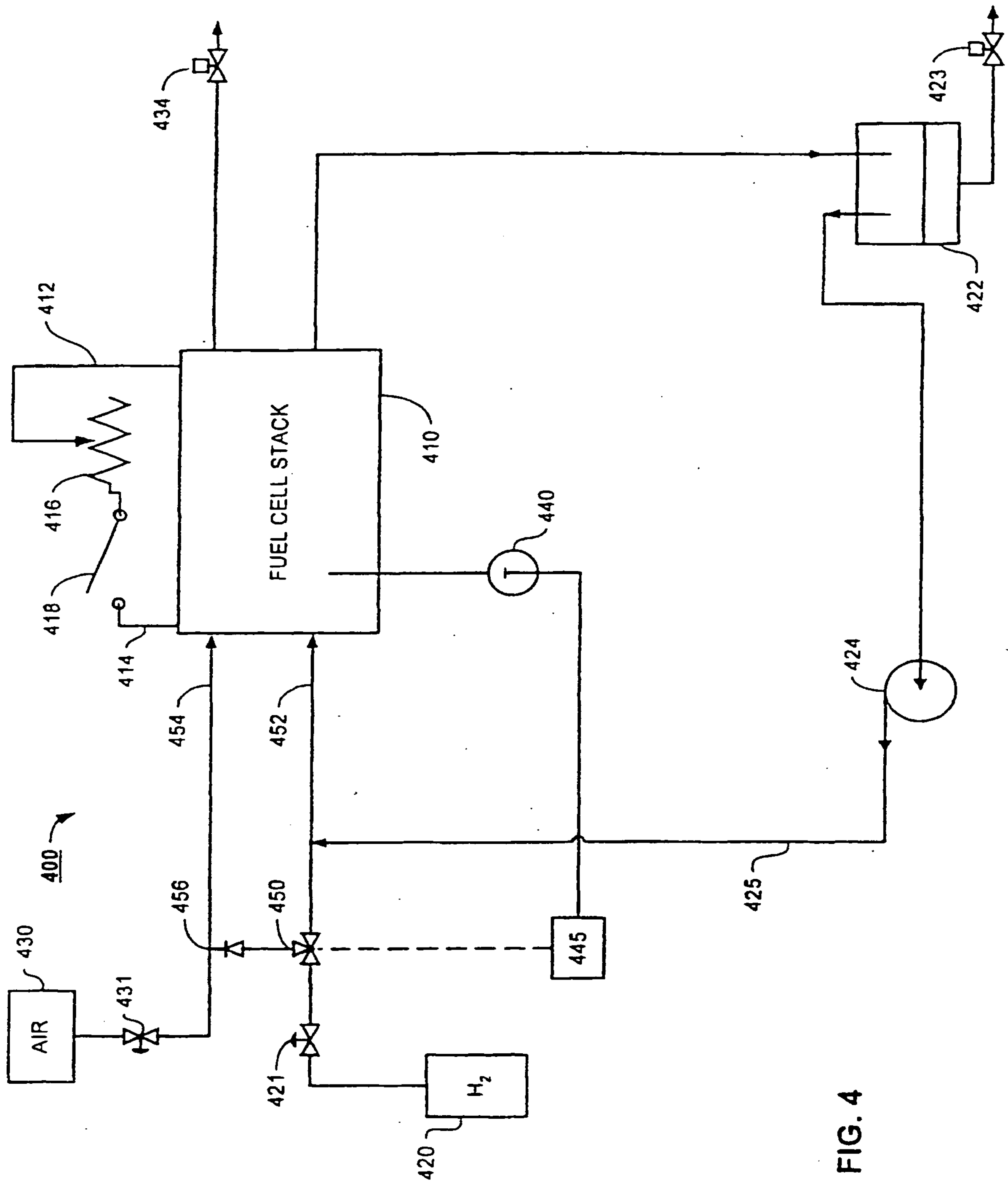
FIG. 3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FUEL CELL STACK
410
412
414
416
418
AIR
430
431
434
H2
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421
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FIG. 4

# INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 00/01500

**A. CLASSIFICATION OF SUBJECT MATTER**
IPC 7 H01M8/04

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H01M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

PAJ, EPO-Internal, INSPEC, CHEM ABS Data

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

| Category ° | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| X | PATENT ABSTRACTS OF JAPAN vol. 010, no. 363 (E-461), 5 December 1986 (1986-12-05) -& JP 61 158672 A (FUJI ELECTRIC CO LTD), 18 July 1986 (1986-07-18) abstract | 1-4,26, 27 |
| X | PATENT ABSTRACTS OF JAPAN vol. 010, no. 065 (E-388), 14 March 1986 (1986-03-14) -& JP 60 216469 A (MATSUSHITA DENKI SANGYO KK), 29 October 1985 (1985-10-29) abstract | 44,45, 47,48,53 |

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

| Date of the actual completion of the international search | Date of mailing of the international search report |
|---|---|
| 16 March 2001 | 04/04/2001 |

| Name and mailing address of the ISA | Authorized officer |
|---|---|
| European Patent Office, P.B. 5818 Patentlaan 2<br>NL – 2280 HV Rijswijk<br>Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,<br>Fax: (+31-70) 340-3016 | D'hondt, J |

Inte ional Application No
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

| Category ° | Citation of document, with indication,where appropriate, of the relevant passages | Relevant to claim No. |
|---|---|---|
| A | PATENT ABSTRACTS OF JAPAN<br>vol. 013, no. 018 (E-704),<br>17 January 1989 (1989-01-17)<br>-& JP 63 225477 A (MITSUBISHI ELECTRIC CORP), 20 September 1988 (1988-09-20)<br>abstract<br>--- | 1,26,27 |
| P,A | US 6 127 056 A (WHEELER DOUGLAS J ET AL)<br>3 October 2000 (2000-10-03)<br>claim 5; figure 1<br>--- | 1,26,27 |
| P,A | US 6 103 410 A (WHEELER DOUGLAS J ET AL)<br>15 August 2000 (2000-08-15)<br>claim 6; figure 1<br>----- | 1,26,27 |

# INTERNATIONAL SEARCH REPORT

Information on patent family members

Int ional Application No
PCT/CA 00/01500

| Patent document cited in search report | Publication date | Patent family member(s) | Publication date |
|---|---|---|---|
| JP 61158672 A | 18-07-1986 | NONE | |
| JP 60216469 A | 29-10-1985 | NONE | |
| JP 63225477 A | 20-09-1988 | NONE | |
| US 6127056 A | 03-10-2000 | NONE | |
| US 6103410 A | 15-08-2000 | NONE | |